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The Portuguese Astronomical Activity in the Late 18th and Early 19th Centuries

Fernando B. Figueiredo*

Abstract
In the late 18th century and beginning of the 19th century, the Portuguese centre of gravity for astronomical research (and teaching) was the Royal Astronomical Observatory of the University of Coimbra. This scientific establishment was envisioned under the Pombaline reform of the University of Coimbra in 1772. Linked to the new Faculty of Mathematics, the Observatory played a pivotal role in the formation of the community of Portuguese astronomers during the first decades of the 19th century. In this paper, we will put in context the scientific work carried out at the Observatory, following the practice of the most famous observatories of Europe, then we will examine how the astronomical work of Monteiro da Rocha, which encapsulated theoretical and practical astronomy, was tuned with the major astronomical problems of that time.

Keywords: Portugal, 18th century, enlightenment, sciences mathematics, astronomy, Pombalina Reform, José Monteiro da Rocha, observatory, ephemerides.

Résumé
Au tournant du XIX[e] *siècle, le centre de gravité portugais de la recherche (et de l'enseignement) astronomique était l'Observatoire royal astronomique de l'Université de Coimbra, établissement scientifique créé sous la réforme Pombalina de l'Université de Coimbra en 1772. Relié à la nouvelle Faculté de Mathématiques, l'Observatoire joua un rôle central dans la formation de la communauté d'astronomes portugais pendant les premières décennies du XIX*[e] *siècle. Dans cet article, nous étudierons le travail scientifique effectué à l'Observatoire, notamment par rapport aux pratiques développées dans les observatoires les plus reconnus d'Europe, puis nous analyserons comment le travail astronomique de Monteiro da Rocha, à la fois théorique et pratique, faisait écho aux problèmes astronomiques fondamentaux de cette époque.*

Mots-clés : XVIII[e] *siècle, Lumières, sciences mathématiques, astronomie, Réforme Pombalina, José Monteiro da Rocha, observatoire, éphémérides.*

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In the 18th century, particularly in its second half, astronomy developed around what is called the Newtonian program. This program is characterised by an intimate relationship between observational astronomy (astrometry) and the advances in theoretical astronomy (celestial mechanics) provided by the work of theoretical astronomers and mathematicians such as D'Alembert (1717-1783), Euler (1707-1783), Clairaut (1713-1765), Lagrange (1736-1813), and Laplace (1749-1827). Therefore, the scientific program of the major (national) astronomical observatories of the late 18th and early 19th centuries was characterised by a constant quest for accurate measurements of the positions of solar system bodies and stars, which would be able to contribute to the improvement of Newtonian theory and the mathematical tools involved in it. Concerning this particular issue, Laplace wrote:

> Astronomy, considered in the most general manner, is a great problem of mechanics, in which the elements of the motions are the arbitrary constant quantities. The solution of this problem depends, at the same time, upon the accuracy of the observations, and upon the perfection of the analysis. It is very important to reject every empirical process, and to complete the analysis, so that it shall not be necessary to derive from observations any but indispensable data. (Laplace, 1798, vol. 1, p. i)[1]

In this ongoing process (the development of instrumental methods of observation, observational data reduction and refinement of the theory) astronomical practice focused mainly on the angular measurement of right ascensions and declinations of celestial bodies passing observatories' meridians – which Jim Bennett calls an international meridian program consensus:

> Thus programs of meridian measurement came to be pursued in all the active observatories of Europe [...] they [the observational data] were accumulated by the activity that became the sine qua non of an astronomical observatory. (Bennett, 1992, p. 1)

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[1] "L'astronomie, considérée de la manière la plus générale, est un grand problème de Mécanique, dont les éléments des mouvements célestes sont les arbitraires ; sa solution dépend à la fois de l'exactitude des observations et de la perfection de l'analyse, et il importe extrêmement d'en bannir tout empirisme et de la réduire à n'emprunter de l'observation que les données indispensables." The English translation is from the translation of Laplace's *Mécanique céleste* by Nathaniel Bowditch (Boston, Hilliard, Gray, Little and Wilkins, 1829).

In Portugal, it was only after 1772, when the Pombaline Reform of the scientific studies in the University of Coimbra took place, that Portugal became seriously engaged with this global astronomical program. In fact, we can say that this Reform, along with the consequent creation of the Royal Astronomical Observatory of the University of Coimbra (henceforth OAUC) were the starting point of structured and consistent institutionalised astronomical activity (teaching/research) in Portugal.

Nevertheless, we can see that the period between the 1720s and the 1730s as the time when an astronomical activity, not attached exclusively to astronomical nautical issues, had emerged within the context of scientific and educational activities of the Society of Jesus, in Portugal.

The Context of Portuguese Astronomy in the First Half of the 18th Century

Until very recently, Portuguese historiography characterised the period of about 200 years after Pedro Nunes (1502-1578)[2] and until Pombal's modernising reforms of scientific education as being a period of actual and absolute stagnation. The Jesuits, as leaders of the Portuguese educational system, were the main culprits.[3] Recently, several and important studies began to overthrow that conventional narrative.[4]

In the first half of the 18th century, astronomy and mathematics were studied in two distinct locations: at the University of Coimbra and the Jesuit College of Santo Antão in Lisbon, in a class called *Aula da Esfera*.[5] In this period, while mathematical and astronomical studies went through a phase of decline at the University of Coimbra, Santo Antão College witnessed a more prosperous phase. Although the Society of Jesus had also been established in other European countries, in Portugal, their pedagogical action was wary of the ideas of the scientific revolution.[6] Scholastic philos-

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[2] Regarding the works of Pedro Nunes, see the article by Bruno Almeida in this volume.

[3] The Jesuits arrived in Portugal in 1540, and from that time onwards they opened various schools for the education of youth. By 1759 they had more than 40 schools (as well as one university, in Évora) which offered free education to more than 20,000 pupils (in an estimated population of 3 million). The University of Coimbra, although it did not belong to them, was greatly influenced by the Jesuit Colégio das Artes, a college devoted to the preparation of university studies.

[4] About the teaching of mathematics within the Jesuit colleges from 1640 onwards see (Baldini, 2004); about the teaching of mathematics and astronomy at Santo Antão see (Albuquerque, 1972).

[5] For the *Aula da Esfera* between 1590 and 1759, and the course of mathematics at Colégio de Santo Antão, see (Leitão, 2008).

[6] About the scientific panorama of Portugal before 1772, see (Martins, 1997).

ophy was widely taught in their Portuguese schools, the *Aula da Esfera* being an exception. Also, everything suggests that in the Brazilian Jesuit College of São Salvador de Bahia the teaching of scientific subjects was at a high level. José Monteiro da Rocha (1734-1819), who was to be one of the main designers of the new curricula for mathematics and astronomy within the scope of University Reform, undertook his studies there.

If the the Portuguese Jesuits' trend of teaching was, in fact, scholastic and assumedly averse to new scientific theories, it is nonetheless true that some men within the Society were aware of the most progressive scientific ideas of their time. The problem consisted in the ossification and rigidity of their thinking, along with their lack of openness to the ideas of Bacon, Descartes, Pascal, Galileo, Huygens, and Newton. In this respect, the Jesuits lost greatly to their rivals: the Oratorian Fathers. Generally speaking, the Oratorians embraced and incorporated the 'new science' within the organisational and pedagogical education system of their colleges (Carvalho, 1985a; Martins, 1997).

During the reign of King João V (1689-1750), the Portuguese scientific scene began to change. The improvement of the economic situation, allowed by the huge amount of gold coming from Brazil, began to foster a new cultural attitude. During this period, the dissemination and consolidation in Portugal of the new scientific ideas were mainly due to the *'Estrangeirados'*, an informal network of Portuguese men, mainly dilettanti and polymaths, who were in contact with European cultural and intellectual circles (many of them were sent by the king himself to establish diplomatic and scientific contacts with other countries and institutions).[7] This enlightened elite of *Estrangeirados* was largely responsible for the translation into Portuguese of some landmarks of the new sciences in the first half of the 18th century.

King João V gave particular attention to astronomy.[8] In 1722, with the aim of conducting a survey on of the Portuguese territories in South America, the king hired two Italian Jesuits astronomers, Giovanni Baptista Carbone (1694-1750) and Domenico Capassi (1694-1736). Carbone, who was to stay in Lisbon, founded the Royal Palace of Ribeira (Paço) Astronomical Observatory (1722-1755) and the Astronomical Observatory of the

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[7] In (Carneiro *et al.*, 2000), the authors argue "that given their heterogeneous social origins, backgrounds and careers, they should not be seen as a homogeneous group. Rather, they were part of a fluid network, although they did not consider themselves as such. What they definitely shared was a common scientific culture", p. 1.

[8] See the article by Luis Tirapicos in this volume.

College of Santo Antão (1723-1759), with instruments coming mainly from France and England (Simões *et al.*, 1999).

Carbone was the first man in Portugal to make astronomical observations (a lunar eclipse on November 1, 1724) in a place intended for that purpose. For about eight years (1724-1732), Carbone was very active with regard to astronomical observations, exchanging correspondence with some European astronomers, mainly Joseph-Nicolas Delisle (1688-1768). He was elected member of the Royal Society (1729), publishing many of his astronomical observations in the *Philosophical Transactions* (Carvalho, 1956).

In the 1750s, there was intense astronomical activity in Portugal with João Chevalier (1722-1801), Miguel Pedegache (1730?-1794), Manuel Campos (1681-1758) and Soares de Barros (1721-1793)[9] at the Astronomical Observatory of the Congregation of the Oratory that was established in Lisbon at the Palàcio das Necessidades (1750-1768).[10]

During the reign of King José I (1714-1777), and prior to the expulsion of the Jesuits (1759), it is worth noting the astronomical activity of the Jesuit Eusébio da Veiga (1718-1798), the last teacher at the *Aula da Esfera* (1753-1759), who published in 1758, in Lisbon, an astronomical ephemerides for the years 1758, 1759 and 1760, named *Planetário Lusitano.*[11] It was followed by a period of about fifteen years during which all astronomical activities virtually ceased.[12] After the Pombaline Reform of the University, astronomical science would undergo an impulse like it had never experienced in the past.

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[9] Joaquim José Soares de Barros studied and worked with Delisle at the observatory of the Hotel de Cluny (his observations on the transit of Mercury on May 6, 1753 were read by Delisle in the Académie royale des Sciences). Soares de Barros was elected corresponding member at the Académie royale des Sciences in Paris and of the Royal Academy of Sciences and Fine Arts in Berlin.

[10] João Chevalier became a corresponding member at the Académie royale des Sciences, where his observation of Halley's Comet on May 4, 1759 was read.

[11] The *Planetário Lusitano* was calculated, within the paradigm of the Tycho Brahe's model, for the meridian of Lisbon (probably the Santo Antão observatory's meridian) and consisted of 3 sheets per month with the ephemeris in true time of (I) the Sun, (II) the Moon, and (III) positions of the planets (Mercury, Venus, Mars, Jupiter and Saturn).

[12] With the exception of some observations made by António Miguel Ciera (1726-1782) between the years 1761-64, and by Soares de Barros: see (Carvalho, 1985b, p. 74-79, 110-111).

Pombal's University Reform (1772): the Creation of the Faculty of Mathematics and the Royal Astronomical Observatory of the University of Coimbra

The reforms of the Portuguese educational system were one of the most important features of the internal politicies carried out by King José I and his prime minister Sebastião José de Carvalho e Melo, Marquis of Pombal (1699-1782). The Reform of 1772 intended to make the University not only a teaching centre but also a centre for the production of knowledge that would meet the technical and scientific needs of the country. According to Gomes Teixeira, the Statutes of the Reformed University are:

> [a] remarkable dissertation about the teaching of sciences, delightful both in depth and form and a monument to healthy pedagogy and high philosophy, (…) where students are wisely advised and masters are given healthy precepts. (Teixeira, 1943, p. 180)

The idea of knowledge and science, particularly mathematics, embodied in the 3rd volume of the Statutes (which concerns the faculties of Medicine, Mathematics, and Natural Philosophy) is in perfect line with the ideas of the European Enlightenment, particularly with its French expression. The influence of D'Alembert's *Essai sur les Éléments de Philosophie* (1759) and *Encyclopédie* (1751-1772), one of the most significant editorial projects of the Enlightenment, is unequivocal.[13]

In fact, the establishment of scientific education at the University of Coimbra was one of the most important features of that Reform. One of the most salient accomplishments was the creation of the Faculty of Mathematics and the Royal Astronomical Observatory. It was the first Portuguese, university-based astronomical observatory. However, it also had characteristics of a national observatory.

The creation of the Mathematics Faculty (the first in the world) could be seen as a necessary consequence of a wider mathematical development across Europe. In the particular case of the astronomy chair, the University Statutes said:

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[13] The entire ideology that underlies the program of the different science courses, particularly those relating to the structure of the mathematics syllabus, strongly materialised the scientific matrix corpus of the French Enlightenment, reflecting the ideas of d'Alembert, as well as other French authors (such as the authors of the textbooks that were adopted, Bézout, Bossut, Marie, Lacaille, Lalande). On the influence of the French Enlightenment in the Reform of the University of Coimbra see (Figueiredo, 2011, p. 45-91; Saraiva, 2015).

> The advantages that result from studying Astronomy, with all parts of mathematics on which it depends, are of such great importance for the progress of human knowledge, particularly for Geography and Navigation. Astronomy has attracted the attention of all kings, who order the construction of Magnificent Observatories for the advancement of that science. (Universidade de Coimbra, 1772/1972, vol. 3, p. 213)

The syllabus of the mathematical course included seven disciplines (4 in the Faculty of Mathematics and 3 in the Faculty of Philosophy). In the first and second years, the disciplines of pure mathematics were taught, while in the last two, mixed or applied mathematics were more focused on.[14] Geometry and Algebra consisted of arithmetics, geometry, trigonometry, algebra, and differential and integral calculus. The third year curriculum consisted of the study of kinematics and dynamics, hydrodynamics, acoustics, and optics (which included the study of optical instruments). Although considered a branch of applied mathematical physics, "applied to the movement of the celestial bodies", Astronomy was studied separately in the 4th year. This disposition was justified by its vastness as a subject of study and its own importance within the mathematical sciences. The study of Astronomy included the history of astronomy; spherical trigonometry (spherical astronomy), the study of physical astronomy, including planetary movements, the three-body problem and theory of the Moon, comet movements, solar and lunar eclipses, and transits of Venus and Mercury. The students were expected to acquire skills in the use of the observational instruments and its vastness as a subject of study knowledge of astronomical calculations at the astronomical observatory – "throughout this course, the theory and the practice should always be studied together", reinforce the Statutes (Universidade de Coimbra, 1972, vol. 3, p. 195).

- *The Royal Astronomical Observatory of the University of Coimbra (OAUC)*

The role and practice required of the Observatory by the University Statutes established a particular dichotomy: as an astronomical university observatory versus a national observatory.[15] Its creation went much further than a simple facility for the teaching and practice of the astronomy course.

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[14] 1st year: Geometry, Rational Philosophy and Moral and Natural History; 2nd year: Algebra and Experimental Physics; 3rd year: Physics-Applied Mathematics; and in the 4th year: Astronomy. There was also a discipline of Drawing and Architecture that could be taken in the 3rd or 4th year.

[15] Regarding this concept of national versus university observatories see (Hutchins, 1999, vol. 1, p. 4-22).

The observatory was not only meant for students to carry out their astronomy practice. In fact, it was above all for professors and astronomers to conduct regular observations and to investigate fundamental astronomical measurements (astrometry) and theories (celestial mechanics). There was a higher purpose: the creation of a national astronomical observatory to publish its own ephemeris and to develop astronomical science.

The problem of determining longitude, both on land and at sea, was a central issue of astronomical and nautical science in the 18th century (Andrewes, 1993; Boistel, 2003). And the conception, calculation, and elaboration of astronomical ephemerides were one of the main objectives of the major European astronomical observatories until the 1820s or 1830s. Those questions were also the basis for the creation of the Royal Astronomical Observatory of the University of Coimbra. In fact, after the OAUC came into full operation in 1799, all its activity focused on the elaboration/development of its own astronomical ephemeris. The 7th paragraph of the Law Charter of OAUC (December 4, 1799) establishes unambiguously the calculus of the astronomical ephemerides as its main scientific purpose:

> The Astronomical Ephemeris should be calculated for the meridian of the Observatory, for its own use (a common practice of the most famous Observatories of Europe at this time), and for the use of Portuguese mariners; the Ephemeris should not be reduced or copied from the English Nautical Almanac, or from any other, but calculated immediately from the Astronomical Tables. (EAOAUC, 1803, p. viii)

The University statutes mandated the immediate construction of the observatory, although the OAUC was operational only after 27 years.

The first architectural plan (c.1773) was designed for the site of Coimbra's Castle, situated on the slope of the city not far from the University.[16] Unfortunately, all the construction works were suspended in 1775, largely because of the high cost of the works. The construction of the observatory in the Castle would never be resumed.

The problematical lack of a real and effective astronomical observatory in which to undertake real scientific research required a solution that developed around the years 1785-1787.[17] On February 5, 1791, the

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[16] This plan was for a large two-storey building (a façade of 58m and a height of 37m), in the middle of which the tower would rise.

[17] In 1775-1776 Francisco de Lemos (1735-1822), the University's rector, ordered the construction of a provisional observatory inside the University backyard to serve teaching purposes. This small building, which was demolished during the

University Council approved the new architectural plan for the construction of the definitive OAUC, and in 1799, the building, consisting of a horizontal body with a flat roof and a central tower with three floors (a front of 41m, a side of 11m and a height of 24m), was completed and ready for research to begin.[18]

The conclusion of this long process (1788-1799) of the definitive construction and foundation of the OAUC was entirely the responsibility of José Monteiro da Rocha, at the time Vice-Rector of the University and Professor of Astronomy.

José Monteiro da Rocha and the Scientific Activity of the OAUC

In fact, the role played by José Monteiro da Rocha was not restricted to the planning and construction of the OAUC, or even its subsequent astronomical activity, which made him one of the most recognised mathematicians and astronomers of Portugal during the late 18th and early 19th centuries. Actually, his importance dates back to 1770-1772, when he was one of the chief minds behind the creation of the scientific teaching structure undertaken by the Pombaline reform. The creation of the Faculty of Mathematics (vision, organisation, syllabus, etc.) was of his own responsibility.

Very little is known about Monteiro da Rocha's youth.[19] It is known that he joined the Jesuits in his younger years (1752) and left Portugal to go to Brazil where he studied at the Jesuit College of Salvador da Bahia (1752-1759). Following the expulsion of the Jesuits in 1759, Monteiro da Rocha left the Society of Jesus and later returned to Portugal (c. 1766). In 1771, he was called by Pombal to participate in the Educational Reform of the University. From this point on he was the lecturer in charge of the courses in Physics and Applied Mathematics (1772-1783) and Astronomy (1783-1804) at the University of Coimbra. In 1795, he was appointed dean and permanent director of the Faculty of Mathematics and Director of the Observatory (then under construction). He was also vice-rector of the University from 1786 to 1804. In 1800 Monteiro da Rocha became a member of the royal council of Prince Regent João VI (1767-1826). In 1804 he became the tutor of Prince Pedro (1798-1834) (future Emperor of Brazil and King of

construction of the definitive OAUC, never had the physical and material conditions for an effective, scientific astronomical research.

[18] For a detailed description of the construction of the OAUC and its instruments see (Figueiredo, 2014, p. 305-310, 313-317, app. p. 52-71; Figueiredo, 2015).

[19] About Monteiro da Rocha’s life and scientific work see (Figueiredo, 2011, 2014).

Portugal, as Pedro IV) and moved to Lisbon where he died on December 11, 1819.

His scientific work covered quite different mathematical and astronomical domains. The most significant part of his astronomical work was developed in the context of his academic career. As director of the OAUC, his work comprised of theoretical and practical. He was the scientific mentor behind the applied mathematical and astronomical methods, algorithms, and tables that allowed the OAUC to establish and publish its most important and significant scientific production : the *Ephemerides Astronomicas do Real Observatório Astronómico da Universidade de Coimbra* (henceforth EAOAUC) (Astronomical Ephemerides of the Royal Astronomical Observatory of the University of Coimbra). He also published works on the determination of comet's orbits; several papers on the calculation of eclipses and on longitude; astronomical tables of the sun, moon and planets and charts of Jupiter satellites; and papers on the use of the rhomboidal reticle and the calibration of the transit instrument. Some of these works were later translated and published in France by Manuel Pedro de Melo (1765-1833) (Rocha, 1808).

Manuel Pedro de Melo, a former student of the University and PhD in mathematics (1795) who became professor of the Royal Navy Academy, was sent to Europe to organise the discipline of Hydraulics, for which he had been appointed at the University in 1801. In France, in the 1800s, he worked with Jean-Baptiste Delambre (1749-1822) at the Observatory of Paris. As a result of this connection, Delambre wrote a small number of reviews of EAOAUC's volumes.[20] This visit by Pedro Manuel de Melo was in line with the statutes of the OAUC (December 4, 1799), which established scientific visits to astronomical observatories and other foreign scientific institutions on a regular basis (every ten years), in order to improve and exchange knowledge and scientific practice.

The charter of April 1, 1801, which initiated the creation of created the discipline of Hydraulics also created that of Practical Astronomy. At the time, the Faculty of Mathematics was facing new challenges which demanded new scientifically updated answers, and the implementation of these disciplines was an attempt to provide them. The creation of the latter was closely related to the future activity of the OAUC, inaugurated in the meantime, which involved working "assiduously in more accurate observa-

[20] CDT pour 1806, "Auteurs d'éphémérides", p. 412; CDT pour 1808, "Sur les éphémérides de Coimbre", p. 454; CDT pour 1809, "Sur les éphémérides de Coimbre année 1807", p. 459; CDT pour 1809, "Formule de M. Monteiro pour les éclipses", p. 459.

tions, to contribute, verify and rectify the Astronomical Tables [...] and to cooperate with more accredited European Observatories" (EAOAUC, 1803, p. viii). Hydraulics was connected to some important hydraulic engineering public works undertaken at the time by the government, chiefly the construction of Aveiro's bar (1781-1808) and the channelling of the Mondego River (1788-1808), for which the Faculty of Mathematics had been asked technical advice.

- *The Astronomical Ephemeris of the Coimbra Observatory (EOAUC)*

After its inauguration in 1799, the scientific activity of the OAUC was entirely focused on the calculations and publications of the EAOAUC. The charter of the OAUC (authored by Monteiro da Rocha and published on December 4, 1799), which established the staff, and its functional competencies and objectives, clearly states that all activity should start with the essential tasks for the preparation of the astronomical ephemerides for the year 1804 onward (EAOAUC, 1803, p. viii). According to these regulations, the entire teaching activity was completely minimised, so as not to interfere with the daily astronomical observations and practices of the OAUC. There is no doubt that this legislation reinforces the national, astronomical characteristics of the OAUC.

The first volume of the Coimbra's astronomical ephemeris was published by Coimbra's University Press in 1803 with all the conventional astronomical information for the following year (12 pages for each month).[21]

From the beginning, the EAOAUC adopted some particularities. They were calculated in reference to the mean Sun and not to the true Sun, used the 360° measure and not the widely-used zodiac signs, and they adopted a particular interpolation method to calculate the ephemeris of the Moon.[22] Unlike the foreign ephemerides, like the French *Connaissance des Temps* (CDT) or the English *Nautical Almanac* (NA), where the positions of the Moon were calculated for both noon and midnight directly from the astronomical tables, at the EAOAUC, only the noon position was directly calculated from those tables, with the position for midnight calculated using

[21] Sun ephemeris (page I): longitude, right ascension, declination, equation of time, semi-diameter, time passing over meridian, hourly motion, horizontal parallax; observations and astronomical phenomena (page II); Planets ephemeris (page III): Mercury, Venus, Mars, Jupiter, Saturn, Uranus; Moon ephemeris (pages IV-VII): longitude, latitude, declination, right ascension (0h and 12h), horizontal parallax, semi-diameter, moon phases; Lunar Distances to Sun, stars and planets (pages VIII-IX); eclipses of Jupiter's satellites and their configuration (page X).

[22] For a detailed study on this method, see (Figueiredo, 2014b).

a particular interpolation method proposed by Monteiro da Rocha.[23] This method, which used finite differences up to the 8th order, also served to calculate the lunar distances to other instants (in the EAOAUC the lunar distances were tabulated every 12 hours). Similarly, to the CDT, or the NA, the EAOAUC also published scientific articles, most of them written by Monteiro da Rocha.

The first volumes of the EAOAUC were calculated using the astronomical tables published by Lalande in his *Astronomie* (3rd edition, 1792), except the positions of planet Mars, which were calculated using tables composed by Monteiro da Rocha himself in 1802.[24] The positions of the Sun and Moon published between 1807 and 1813 were calculated upon the tables of Burg and Delambre, published by the *Bureau des Longitudes* in 1806. In 1813 Monteiro da Rocha published *Taboas Astronomicas ordenadas a facilitar o calculo das Ephemerides da Universidade de Coimbra* (astronomical tables to facilitate the calculation of the EAOAUC), which would be the basis for calculating the EAOAUC until the mid-19th century.

Due to its characteristics, the EAOAUC was actually more oriented towards the activity of astronomers and their observatories than towards sailors and nautical astronomy. Navigators, especially in the merchant navy, preferred to use the *Ephemerides Nauticas* (nautical ephemeris) published since 1788 by the Royal Academy of Science of Lisbon because the Coimbra ephemerides were not so appropriate for nautical activities. This *Ephemerides Nauticas* (which we will examine in detail in section 4) was in most part copied from the English Nautical Almanac, but with all data shifted to the Lisbon meridian, presenting the lunar distances tabulated for every three hours.

In 1826, aware of these problems, the interim director of the OAUC, Joaquim Maria de Andrade (1768-1830), started a new section in the EAOAUC, entitled *Calendário Náutico* (nautical calendar). This *Calendário* provided the most important astronomical data "for the convenience of navigators [para a conveniência dos Pilotos]", such as the Sun's declination and right ascension in true time and the lunar distances tabulated every 3 hours, giving the possibility for using the direct proportionality to calculate the Moon's places for other instants. However, this lasted only three years (1825, 1826 and 1827). In 1840, when resuming the EAOAUC's publica-

[23] This method was published on the EAOAUC (1808), p. 121-180.

[24] *Tábuas de Marte para o Meridiano do Observatório Real da Universidade de Coimbra*, EAOAUC (1803) p. i-xv.

tion after a break of 13 years, the Calendar was not inserted and, henceforth, the astronomical character of Coimbra's ephemeris prevailed.[25]

Monteiro da Rocha's Works on the Longitude Problem

The longitude problem is related to the question of finding the time difference between two locations. Nowadays, it can be solved easily with a simple wristwatch, but until the 18th century it was one of the greatest scientific and technical problems. With the need to stimulate a satisfactory solution to this question, the British government offered a series of potential rewards, up to £ 20,000 – the famous *Longitude Act*. By the end of the 18th century, the existence of accurate instruments for measuring the angles between the Moon, Sun or stars, together with accurate stars catalogues and the possibility of creating precise tables of the Moon's motion, paved the way for finding an astronomical solution.

At On the theoretical level, the answer came with the significant development of the *'Theory of the Moon'*, which enabled the construction of very reliable lunar and solar tables.[26] In 1758, Lacaille (1713-1762) published his solar tables and in 1753 Tobias Mayer (1723-1762) produced his tables of the Moon. Later improved by Charles Mason (1730-1786), they were the principal basis for the CDT and NA. The possibility to build accurate astronomical an ephemeris predicting, for instance the passage of the Sun or Moon across a meridian, the occurrence of eclipses, the moment when we can find certain Moon-Sun distances, or Moon-stars (called lunar distances) was a wish come true.

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[25] It is interesting to note that after 1833 the English NA made some changes and started to give its astronomical data in mean time, "The attention of the Committee was, in the first instance, directed to a subject of general importance, as affecting almost all the results in the Nautical Almanac; viz., whether the quantities therein inserted should in future be given for apparent time (as heretofore), or for mean solar time. Considering that the latter is the most convenient, not only for every purpose of Astronomy, but also (from the best information they have been able to obtain) for all the purposes of Navigation; at the same time that it is less laborious to the computer, and has already been introduced with good effect into the national Ephemerides of Coimbra and Berlin, the Committee recommend the abolition of the apparent time in all the computations of the Nautical Almanac; excepting only the place, &c of the sun at the time of its transit over the meridian", *Nautical Almanac* (1833) p. xii. As one of the referees observes this is a very apt example of an influence moving the opposite way from what would usually be expected. We greatly appreciate his/her suggestion for a further development of this subject.

[26] In 1758 Lacaille (1713-1762) publishes its solar tables, which together with Moon tables (1753) by Tobias Mayer (1723-1762), later improved by Charles Mason (1730-1786), will be the principal basis to elaborate the CDT and NA.

In 1759, Lacaille read a memoir at the Académie Royale des Sciences proposing the use of lunar distances as a solution for the longitude problem (Lacaille, 1765). In 1754, he had already presented to the same Academy a work on this subject, '*Projet pour rendre la méthode des Longitudes sur mer praticable au commun des navigateurs*. And he had also expressed his intention to give a nautical connotation to his *Ephémérides des mouvements célestes*. In 1766, the British Royal Astronomer, Nevil Maskelyne (1732-1811), created the *Nautical Almanac* where, for the first time, as Lacaille had proposed, lunar distance tables were published. In 1772, the French CDT also started to publish them, copied from the NA. Only in 1789 did the CDT start to publish its own lunar distances directly computed from observations and astronomical tables. In the following years, the scientific debate around the use of the lunar distances was intense.[27] In 1779, Jean-Charles de Borda (1733-1799) published a protocol that definitively put the lunar-distance method into maritime practice. This method, which became known as the Borda method, was immediately presented in the 1st volume (1788) of the Portuguese *Ephemerides Nauticas* of the Royal Academy of Sciences of Lisbon.[28]

The major practical problem of the lunar-distance method was related to the reduction of the observations (apparent distance to true distance). In the 18th century, the trigonometric equation proposed by Borda's method demanded a substantial calculation effort. As a consequence several direct and indirect methods (trying to reduce the true distance through successive corrective formulas of the apparent distance, taking into account the values of refraction and parallax correction) were proposed (Cotter, 1975, p. 305-328). Mendoza y Rios wrote 40 different formulas and nearly four decades later, Guépratte claimed to know around 100 (Rios, 1801, p. 3-37, 66-77; Guépratte, 1839, vol. 1, p. 219).

The *Cálculo das longitudes* (calculus of longitudes), published by Monteiro da Rocha in the first volume of the EAOAUC (1803, p. 213-230), is essentially a lunar-distance method, it was based on the 'approximation's

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[27] At the time, there were several competing lunar methods. The hour angle method proposed by Pierre C. Le Monnier (1715-1799) and Alexandre Guy Pingré (1711-1796) was one of them. On this subject, see (Boistel, 2003, p. 281-383).

[28] *Método do Cavalheiro de Borda para o cálculo das longitudes no mar, determinadas pelas distâncias da Lua ao Sol, ou às Estrelas* (Cavalheiro de Borda's method for calculating the longitude at sea, determined by the distance of the Moon to the Sun, and the Stars), Ephemerides Nauticas (1788) p. 170-181.

methods for reduction of the observations' set.[29] This method is very similar to another one that he had published in 1799: *Taboada Nautica para o cálculo das Longitudes* (nautical table for longitude calculation).

But there is one of José Monteiro da Rocha's unpublished manuscripts (212 pages) on the longitude problem that should be singled out – *Methodo de achar a Longitude Geográfica no mar y na terra Pelas observaçõens y cálculos da Lua Para o uso da Navegação Portugueza* (Method to be used by the Portuguese Navy for finding the Geographic Longitude at Sea and on Earth by Observations and Calculations of the Moon).[30] A very interesting manuscript on all levels, it was written in the 1760s, at a time when lunar distances became a serious matter in worldwide scientific discussions. It is a deeply researched and reflective work but, more than that, it has a didactic goal since Monteiro da Rocha aspires to introduce navigators into a completely new practice and instruct them about it. So, throughout the manuscript, we can see an author deeply concerned with the intelligibility of everything he writes.

The manuscript is dedicated to "Mr Count of Oeiras, Minister and Secretary of Foreign Affairs of the Kingdom", future Marquis of Pombal, from whom Monteiro da Rocha was seeking support for its publication:

> [with the use of these lunar-distance methods] the Portuguese will have the glory of being the first to implement observations of longitude, they will be the first to open the last frontiers of the world. And the highest price I can get is the glory of our Nation and the usefulness for the fatherland.[31]

The manuscript was begun in Brazil and finished in Lisbon. During his trip back to Portugal (1765), Monteiro da Rocha made a lot of observations, which would help him resolve and improve certain theoretical and practical issues (instrument observations and observation reductions). Monteiro da Rocha devoted particular attention to the problem of errors that can affect the determination of longitude: errors of the instruments and errors from astronomical data conveyed to the astronomical ephemeris. At that time, only a few had dealt with these issues (Boistel, 2006).[32]

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[29] It also presents a version of the method of corresponding heights to particular cases in which it is impossible to observe the luni-solar distances 2, 3 days immediately before and after the full Moon.

[30] This manuscript (henceforth Ms. 511) was found in Biblioteca Nacional, in 2005. Until that time, it was completely unknown.

[31] Monteiro da Rocha, Ms. 511, fl.17v.

[32] Boistel and I will shortly publish a paper about the study of this manuscript by Monteiro da Rocha entitled: 'José Monteiro da Rocha and the international debate

Monteiro da Rocha was acquainted with all the important literature and the principal key authors related to the longitude problem. His bibliography was up-to-date (throughout the text he makes 20 direct bibliographic references).

To Monteiro da Rocha, Lacaille's method had a major disadvantage, being connected to previous computed lunar distances. But, in spite of that, Monteiro da Rocha wrote that this "does not cancel the merit of his method which did not have the promotion it deserved because of Lacaille's death on March 23, 1762".[33]

The five methods proposed by Monteiro da Rocha on the manuscript did not make use of lunar distances but of the Moon's longitude.[34] They are all based on the determination (calculation) of the celestial longitude of the Moon at the time of observation and they all refer to comparison with the tabulated values in nautical ephemeris in order to determine the corresponding time of the meridian of Lisbon (or the geographical longitude referred to Lisbon). While this can be seen in some ways as an advantage the calculation effort required by it, as a matter of fact, was truly underestimated at a time when all these matters were new.

Monteiro da Rocha, besides some auxiliary tables to help with calculations, also proposed a nautical almanac with the Moon's ephemeris, calculated in mean time, every four hours, for the meridian of Lisbon.[35] As an example, and as a future model for that nautical ephemeris, he presented some tables with the astronomical data for Sun and Moon on the 25th, 27th, 29th, and the 31st of December of 1767, for the meridian of Lisbon.[36]

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in the 1760's on the astronomical methods to find longitude at sea: its proposals and criticism of the method of lunar distances of Lacaille', to be published in 2017.

[33] Monteiro da Rocha, Ms. 511, fl.15v.

[34] The first two are variants of the methods of corresponding heights, and the other three variants of the method of lunar distances.

[35] Sun's ephemeris: longitude, right ascension and declination; Moon's ephemeris: longitude, right ascension, declination, horizontal parallax and horizontal semidiameter; time equation.

[36] Aware of the importance of building astronomical tables with a high degree of accuracy, he wrote, "The actual theoretical progress is of great perfection [...]. Mayer's lunar tables calculated on the principles of Euler, and Clairaut's tables are of extraordinary accuracy, it is rare to have a minute in difference when compared with the more accurate observations of the Moon", Monteiro da Rocha, Ms.511, fl.14. We have in preparation a book about the Ms.511 manuscript where we will give details about the accuracy of these tables.

The manuscript ends with a stellar catalogue with right ascension, declination, and annual variation of about 70 stars.

- *The Determination of the Orbits of Comets*

There is another work by Monteiro da Rocha that is worth mentioning n the determination of the orbits of comets. It was published only in 1799, two years after Olbers's famous work on the same subject[37] was published, but in reality, its manuscript dates back to 1782.[38]

Already in his youth, at the age of 25, Monteiro da Rocha had written a small work on comets. It was a didactic text about the nature and orbits of comets, written on the occasion of the return of Halley's Comet in 1759, which he observed in S. Salvador de Bahia, Brazil, between 13th of March and late April, without realising that it was the famous comet.[39] The Comet's return would be a crucial test for Newton's theory and Monteiro da Rocha, a confident Newtonian. Well aware of this, he took the opportunity to spread didactically the gravitational theory of the English scientist. This text consists of two distinct parts. In the first, he examines "the sentences of the most famous philosophers and mathematicians showing that comets are true celestial bodies as old as rest of the heavenly bodies". Monteiro da Rocha summarises and criticises a set of scholastic theories on the nature of comets that described them as malevolent supernatural beings and not natural heavenly bodies. At the same time (1757-1759), other Portuguese men wrote on the same subject: (e.g. Miguel Tibério Pedegache (1730-1794), Bento Morganti (1709-?) and Francisco Henrique Ahlers (?-?) but, unlike Monteiro da Rocha they are somewhat confused and sometimes reserved in the defence of modern ideas. In the second part, entitled "Practical Astronomy in Order to Calculate the Motions and Comets' Ephemerides", Monteiro da Rocha presents the most common methods in use in the first half of the 18th century for comets' orbit calculation (basically geometrical methods). In several aspects, namely in defence of Newton's ideas and the mathematical part about orbit determination we can say that

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[37] (Olbers, 1797) was published under the sponsorship of Franz X. Freiherr von Zach (1754-1832). A few years later, under Olbers's supervision, it was translated into English and published by the Royal Institution. In 1847, it was republished by Johann F. Encke (1791-1865).

[38] (Rocha, 1799). However, this work was first presented and read by Monteiro da Rocha to the Academy much earlier, on January 27, 1782.

[39] José Monteiro da Rocha (1760), *Systema Physico Mathematico dos Cometas* [manuscript, BPE, FM-506]. In 2000 the manuscript was publishded in Brazil : (da Rocha, 2000).

Systema Physico Mathematico dos Cometas is unique in the history of Portuguese astronomy of the first half of the 18th century.

However, his memoir of 1782/99 is completely different. It is a real scientific work on one of the major astronomical problems that had occupied many astronomers and mathematicians for over a century. In his *Principa* (1687) Newton had considered the determination of the orbits of comets as a *'Problema hocce longe difficillimum multimode aggressus'* (Newton, 1687, p. 492) and from that time on was studied by the most famous astronomers and mathematicians of the 18th century, such as Euler (1707-1783), Clairaut (1713-1765), D'Alembert (1717-1783), Condorcet (1743-1794), Boscovich (1711-1787), Pingré (1711-1796), Prosperin (1739-1803), Lalande (1732-1807), Lambert (1728-1777), Lagrange (1736-1813), Laplace (1749-1827), and others.

In 1772, the Berlin Academy of Sciences proposed a prize to be awarded in 1774 to anyone who discovered a simple method to determine the parabolic orbit of a comet using only three observations. This award was only granted in 1778 to Condorcet and Tempelhoff (1738-1808).[40] Nevertheless, it was Olbers who got the historical credit as the inventor of a simple and easily applicable method for this problem.

Monteiro da Rocha, in his academic memoir, presents an identical analytical method to Olbers'. The differences between the methods lie in the fact that Monteiro da Rocha's make use of an approximate relation between the geocentric distances of the middle position and the terminal position of the comet, and of the Euler-Lambert equation, not in its habitual form, but one obtained by squaring the two members of the theorem, while Olbers's is characterised by the employment of an approximate relation between the geocentric distances of the terminal positions of the comet and of the straight application of the theorem of Euler-Lambert.

Although the publication of Olbers's work had preceded Monteiro da Rocha's by two years, the timing of the invention of their methods was the reverse. This and the circumstance of having been written in Portuguese, meant that Monteiro da Rocha lost precedence to Olbers.[41] One

[40] Monteiro da Rocha was aware of the Berlin contest but didn't know its outcome. Actually, it was this contest that encouraged Monteiro to study this subject (letter dated of July 17, 1780 to the Academy's Secretary, Academy's Library Archives Ms. Azul 1944).

[41] "It may be said that this was the only method, really worthy of being called like this, which, before that of Olbers, permitted the easy calculation of the orbital elements of a comet given by three observations." (Leite, 1915, p. 66). For a quantita-

thing is sure, however, the names of Monteiro da Rocha and Olbers must, therefore, appear together in the history of astronomy as the first inventors of a practical and easy method for the determination of the parabolic orbits of comets.

The Creation of the Royal Academy of Sciences of Lisbon and the Royal Naval Academy

After the death of King José I, the first years of Queen Maria's reign were somewhat troubled times with regard to University life, facing attacks from the most conservative forces of the society. But after some time, the modernisation effort initiated during the reign of her father continued. During the period known as *Mariano-Joanino*,[42] it can be stated that the government's teaching policy continued to be guided by the Pombaline model, despite the natural wearing down of institutions due to the instability of national life.[43] As Luis Carolino emphasises, the teaching reforms extended to technical education, with the creation of the *Academia Real da Marinha* (Royal Naval Academy) in 1779, and the *Academia Real de Fortificação, Artilharia e Desenho* (Royal Academy of Fortification, Artillery and Drawing) in 1790 (Carolino, 2012). In fact, it is in this period that scientific specialisation began and professional mathematicians, astronomers, engineers, botanists, chemists, and mineralogists emerged, with the Royal Academy of Sciences of Lisbon playing an important part.

The Royal Academy of Sciences of Lisbon (henceforth ACL) was created on December 24, 1779. The founders, João Carlos de Bragança (1719-1806), 2nd Duke of Lafões, being the most important of them, were influenced by Enlightenment values and aimed at using science and technology to develop the country economically and socially.[44] As with similar

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tive comparison of the two methods see (Figueiredo 2005) and for a brief discussion see (Figueiredo & Fernandes, 2006).

[42] This historiographical period covers two reigns: Maria I and João VI. In 1792 Maria I became mentally unstable and her son, prince João (1767-1826) – future king João VI – started to sign in her name. In 1799 the queen was considered insane and the prince took the regency of the kingdom. João VI reigned as king between 1816 and 1826.

[43] War of the Oranges with Spain (1801); the transfer of the court to Brazil (1807), the Napoleonic Invasions (1807-1811), and the country's submission as a British protectorate under the command of the general William Carr Beresford (1811-21).

[44] José Monteiro da Rocha was one of its first members, elected in January 16, 1780.

foreign academies, like Paris, Berlin and St. Petersburg, the ACL promoted scientific studies, mostly in applied science, agriculture, and industry but also in literature, law and Portuguese history. The ACL also had its own prize system, introducing almost every year a set of questions to be answered in a fixed period of usually 2 years, with a gold medal as a reward. Between 1780 and 1822, ACL launched 253 contests concerning observation and physical science (178) and exact science (mathematics, astronomy and navigation) (75). Until now, we have not found any contest for the years 1803-1806, 1809-1810 and 1813-1814 . Therefore, from a set of 34 years of available data, we found a total average of prize tenders of 7.44 per year. Observational and practical sciences being represented more than twice as often as the exact sciences (5.23/year and 2.21/year, respectively) (Figueiredo & Saraiva, 2013). In astronomy, most of the proposal questions were in practical nautical astronomy, the use and construction of nautical instruments (sextant, octants), and on the longitude problem (mostly on the research of other protocols besides that of Borda for lunar distances).

The deep understanding of the physical limits and economic potential of Portugal and its overseas regions in Asia, Africa and America was of much concern to Portuguese government and ACL academicians. Portuguese economic development of its overseas trade was dependent on well-qualified personnel in both naval and merchant fleets. Thus, in 1788, the ACL started to publish its nautical ephemeris, *Ephemerides Nauticas ou Diario Astronomico* (henceforth NE), with which some academicians and professors of the Royal Naval Academy were involved.

The Royal Naval Academy (henceforth ARM) was created in Lisbon in 1779 as a theoretical teaching establishment which set out to prepare navigators for the naval and merchant fleets and army engineers (the ARM operated until 1837). In 1782, a new Academy, the *Academia Real dos Guardas-Marinhas* (Royal Academy of Midshipmen), was also created. This institution had the purpose of training officers for the Portuguese Royal Navy.[45] The program of study for these academies included, among other matters, theoretical and practical mathematics, navigation and nautical astronomy. Its first teachers were graduates of the University of Coimbra.

In 1791, Francisco Antonio Ciera (1763-1814), Professor of Navigation at the ARM, proposed the construction of an observatory for teaching nautical astronomy classes. The Royal Naval Observatory (OAM) was inaugurated in 1798 (its regulation dates back to July 23, 1799) and assumed

[45] In 1807, as a result of the Napoleonic French Invasion, the Academy of Midshipmen followed the king and Portuguese government to Brazil. The Academy returned to Portugal in 1826 and was extinct in 1845.

formal scientific responsibility for the production of the ACL's nautical ephemeris (NE). From its first volume, the NE publication was under the responsibility of the ACL's astronomical observatory, which had been inaugurated in 1787.

- *The ACL's Nautical Ephemeris (NE)*

The ACL's project for the publication of a Portuguese nautical ephemeris started to be discussed among the academicians around 1781, but the first volume was only published in 1788. From the beginning, Monteiro da Rocha did not see any special interest in having a Portuguese nautical almanac as a recalculated copy from CDT or NA for the meridian of Lisbon, as the ACL wanted to do because Portuguese sailors had easy access to those foreign publications. What would be desirable would be to have a Portuguese almanac or ephemeris with lunar distances calculated directly from astronomical tables other

> then those of Mayer's, in which the calculations of the English Nautical Almanac were based, as also its copy of Connaissance des Temps, such as Clairaut's and Euler's tables.[46]

Monteiro da Rocha emphasised that such an almanac would be of interest to all maritime European countries, and would bring glory to Portugal. But at the time, such a project was impossible to carry out due to a lack of national technical and scientific capacity. In fact, it would be carried out by himself some years later at the OAUC.

The NE had 8 pages for each month with astronomical data calculated in apparent time for the Lisbon meridian.[47]

Its first director (1787-1795) was Custódio Gomes Villas-Boas (1744-1808), Professor of Astronomy at the ARM and also the first director of the ACL's astronomical observatory.[48] The next director was José Maria

[46] Letter from Monteiro da Rocha to ACL's Secretary dated October 7, 1781 (ACL's Library Archives, Ms. Azul 1944).

[47] Page I: sun and moon declination; page II: moon birth, moonset, moon's passage over Lisbon's meridian; page III: Mars, Jupiter and Saturn ephemeris (birth, set, passage over the meridian, latitude and longitude) and sun semi-diameter, places of Moon's node; page IV: several astronomical phenomena and Jupiter satellites' eclipses; pages V-VIII: lunar distances. For a comparison between the EAOAUC and the ENACL see (Figueiredo, 2017).

[48] In 1804 Custódio Gomes Villas-Boas together with Francisco António Ciera (1763-1814) translated into Portuguese Flamsteed's famous stellar catalogue, *Atlas Coelestis* (London, 1729) that would be published by ACL: *Atlas Celeste, arranjado por*

Dantas Pereira (1796-1798), also a professor at the ARM. Between 1799 and 1805, the director of the ephemeris was the Frenchman Charles Marie Damoiseau de Montfort (1768-1846).[49] From the beginning until its suspension in 1863, the NE's publication was always the ACL's business.

- *Cartographic Works in Portugal and Brazil*

Since the Portuguese empire was largely maritime, the development of navigation, cartography and hydrographic charts was crucial to maintain and foster it. In the late 18th century, Portuguese government was well aware of the need to have robust and well-prepared merchant and war fleets, to serve as a bridge connecting the continental territory with the vast overseas dominions, promoting the Portuguese economic independence (Simon, 1983); Another important question was the true geographic knowledge of this vast overseas territory.

In the 18th century, the great technological advances in the accuracy of portable instruments and astronomical ephemerides enabled further improvements in cartography. A correct knowledge of inland regions, coasts and ports of the metropolitan and colonial territories, crucial to promote the better exploitation of natural resources and improvement of the efficiency of civil administration, was a matter of state for all European countries of that time.[50] Portugal was no exception. Besides, Portugal was one of the European countries with more scattered territories in Africa, Latin America, and Asia.

Flamsteed, publicado por J. Fortin, correcto, e aumentado por Lalande, e Mechain [...], Lisboa, ACL, 1804.

[49] Damoiseau de Montfort began his career as an artillery officer of the French army, but during the French Revolution he became an *émigré* (1792). In 1795, Damoiseau was in the service of the king of Sardinia in the Piedmont region of Italy. With the arrival of the French troops, he went to Portugal and joined the marine artillery. Back to France around 1808, he developed an extensive work on the tables of the Moon, having been elected a member of the Académie des Sciences, on August 1, 1825. On the death of Johann K. Burckhardt (1773-1825) in that year, Damoiseau took over as director of the observatory of the École Militaire. He was also a member of the Bureau des Longitudes. In 1831, he received the Gold Medal of the British Royal Astronomical Society for his astronomical works. In 1836, he published a set of tables on the satellites of Jupiter: *Tables écliptiques des Satellites de Jupiter [...]* (Paris, 1836), which replaced those of Delambre, and were used for the CDT from 1841 to 1914.

[50] In France, the first modern cartographic survey (known as Cassini's maps) was undertaken between 1744 and 1793, and it would serve as model for future cartographic campaigns in other countries.

As we had already indicated, the arrival of the Italians Carbone and Capassi was related to the demarcation of the Portuguese and Spanish territories in the colony of Sacramento and in the Plate river.[51] As a result of the Treaty of Madrid signed between the two countries in 1750, Miguel Ciera (c. 1726-1782), an Italian from Padua, was hired as a mathematician, astronomer, and geographer to join the team that would establish the limits of southern Brazil. During three years (1752-1756), this team, called *Terceira Partida de Limites*, went up the Paraguay River until they reached the source of the Jauru River, where they put a mark as a symbol of the demarcation of the Portuguese and Spanish lands (Costa, 2009). Ciera was later the first professor of Astronomy at the new Faculty of Mathematics (1772-1778) and Professor of Spherical Trigonometry and Navigation at the ARM (1779-1782). In 1783, he was formally replaced by Monteiro da Rocha in the teaching of Astronomy at the University of Coimbra.

In 1777, another campaign was launched in the same region to undertake new demarcations imposed by the new Treaty of Santo Ildefonso (the Treaty of Madrid was cancelled in 1761). This team was led by Antonio Pires da Silva Pontes (1750-1805) and Francisco José de Lacerda e Almeida (1750-1798), both recent PhDs in mathematics from the University of Coimbra and former students of Ciera and Monteiro da Rocha. A lot of information about the longitude of many places in inland Brazil, and some in Peru, resulting from this cartographic mission were published in the 3rd (1805) and 12th (1815) volumes of the EAOAUC.

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[51] In 1767 Louis-Antoine de Bougainville (1729-1811), on his journey around the world, passed this region and described the situation in the colony: "Before the last war, they carried on a prodigious contraband-trade with the colony of Santo Sacramento, a place in the possession of the Portuguese, upon the left side of the river, almost directly opposite Buenos Ayres. But this place is now so much surrounded by the new works, erected by the Spaniards, that it is impossible to carry on any illicit trade with it, unless by connivance; even the Portuguese, who inhabit the place, are obliged to get their subsistence by sea from the Brazils. In short, this nation bears the same relation to Spain here, as Gibraltar does in Europe; with this difference only, that the former belongs to the Portuguese, and the latter to the English." [Avant la dernière guerre il se faisait ici une contrebande énorme avec la colonie du Saint-Sacrement, place que les Portuguais possèdent sur la rive gauche du fleuve, presque en face de Buenos Aires ; mais cette place est aujourd'hui tellement resserrée par les nouveaux ouvrages dont les Espagnols l'ont enceinte que la contrebande avec elle est impossible s'il n'y a connivence ; les Portugais même qui l'habitent sont obligés de tirer par mer leur subsistance du Brésil. Enfin ce poste est ici à l'Espagne, à l'égard des Portuguais, ce que lui est en Europe Gibraltar à l'égard des Anglais] (Bougainville, 1771, p. 30-31). The translation is from the English edition by John Reinhold Forster, published in 1772.

But it was not only in Brazil that mapping issues were important. The non-existence of good maps of the Portuguese metropolis was also an issue. In Portugal, before the work on the *Carta do Reino* (map of the Kingdom) began in 1790, the maps used were usually adaptations of foreign ones.[52]

The project of creatinfa cartographic map of Portugal began to be discussed in the ACL at the end of 1788. According to the academician Custódio Gomes Vilas Boas, the project was to be coordinated by Monteiro da Rocha, which in fact did not happen. Instead, at the head of those cartographic works was Francisco António Ciera, at that time, professor at the ARM. Francisco Ciera was Miguel Ciera's son and had studied at the Faculty of Mathematics. But Monteiro da Rocha found himself directly involved in the project as the maker of the measuring rods used in the measurements of the main bases of the triangulation network.[53] In 1804, the works were interrupted without the whole country's triangulation being completed. The *Carta do Reino* project was resumed only in 1835 with Pedro Folque (1744-1848), and his son Filipe Folque (1800-1874), himself also a PhD in mathematics from theUniversity of Coimbra. Nevertheless, during the first half of the 19th century, several surveys of different parts and regions of Portuguese territory (mostly of coastal regions and main seaports) were conducted. Those cartographic surveys were designed underneath Ciera's triangulation network.[54] At the same time, some standardisation

[52] One of the most important maps used was the *Mapa dos reinos de Portugal e Algarve* (Map of the kingdoms of Portugal and Algarve), by the Italian Zannoni (1736-1814), printed in Paris in 1762.

[53] "In Portugal no one can help me better than Dr. José Monteiro da Rocha, who was my professor in Coimbra. This man of rare genius, who no doubt can be enrolled in the great European Mathematicians group, can greatly contribute on this expedition. [Em Portugal ninguém pode me ajudar melhor do que o Dr. José Monteiro da Rocha, que foi meu professor em Coimbra. Este homem de gênio raro, que sem dúvida pode ser inscrito no grande grupo matemáticos europeus, pode contribuir muito nesta expedição]", Francisco Ciera in a letter from c.1790, cited in (Mendes, 1965).

[54] In 1801 a specific law was made (chart-in-law June 9, 1801), which intended to create in each district the profession of cosmographer (to a mathematician graduated by Coimbra's University) whose principal work would be to do a topographic survey of that region according to the rules established by the Carta do Reino, and 'intender on all public works [...]'. This law, whose wording is from Monteiro da Rocha, introduced a major reform in the administration of the territory, transferring to new employees of the central administration a set of competencies previously reserved to magistrates. According to Adrien Balbi, this law was inspired by the French model (Balbi, 1822, vol. 2, p. cvj).

procedures regarding scales were implemented (Dias, 2005). An illustrative example is the map of the *Province of Entre Douro e Minho* made by Custódio Gomes Vilas Boas (1771-1809) in 1794-1795 but only published after 1805.[55]

In those mapping and cartographic activities, we must highlight two institutions: The ACL which has already been mentioned, and the *Sociedade Real Marítima, Militar e Geográfica para o Desenho, Gravura e Impressão das Cartas Hidrográficas, Geográficas e Militares* (Royal Maritime, Military and Geographic Society for Drawing, Engraving and Printing of Hydrographic, Geographic and Military maps). The latter was created in 1798 by the Minister of Marine, Rodrigo de Sousa Coutinho (1745-1812), with the explicit goal to prepare and publish hydrographic charts, and military and hydraulic maps of the country. This Society did not last for a long period of time, ending in 1807. Among its members were officers and teachers of the ARM and of the Royal Academy of Fortification, Artillery and Drawing, four royal ministers, and two professors of the University of Coimbra, Monteiro da Rocha being one of them. The aforementioned *Taboada Nautica para o cálculo das Longitudes* (1799) by Monteiro da Rocha was a consequence of the Society's scientific activities.[56]

With regard to the topographic surveys of the country, the first steps were taken by José das Neves Costa (1774-1841) in the 1810s, culminating with the publication of a series of instructions for that purpose in 1840. But only with the creation of the *Direcção Geral dos Trabalhos Geodésicos* (General Directorate of Geodesic Works) in 1852 did that kind of work really start.

Conclusion

The creation of scientific studies established by the University Statutes of 1772, marks, without doubt, the beginning of a new era for Portuguese science. Clearly, this Reform intended to tune the country to the new scientific paradigm that emerged in Europe after the scientific revolution of the 16th and 17th centuries and to recover its delay, putting Portugal side

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55 On the cartographic surveys conducted between 1790 and 1807, see (Dias, 2007).

56 About the work of these individuals and the importance of these questions of longitudes and cartographic works for Portugal and its empire in the late 18th century, we are finishing a paper to be published soon entitled: 'The scientific activity of the Royal Maritime, Military and Geographic Society (1798-1807): making science for the country's and empire's needs'.

by side with the Enlightened Europe of the 18th century. With regards to astronomy, this ambition was undoubtedly fulfilled.

The mathematical course created at the Faculty of Mathematics formalised the teaching of Newtonian astronomy and celestial mechanics in Portugal. And the creation of the Royal Astronomical Observatory of the University, a true national astronomical observatory, promoted the progressive establishment of a future Portuguese astronomical community.

The astronomical activity planned for the OAUC – and effectively undertaken – placed it alongside the major European astronomical institutions of the time, like the Paris and Greenwich Observatories. Nothing similar had previously existed in the history of Portuguese astronomy. The primitive astronomical spaces founded by Jesuits in the reign of João V at Santo Antão College and at the Palace of Ribeira were not comparable in any aspect – not in size, nor as regards its instrument collection, and not even in relation to the astronomical program carried out by the OAUC.

The contribution of Monteiro da Rocha, to whom an entire generation of astronomers from the first half of the 19th century owed a debt, was had a seminal part in this breakthrough. He was a key actor behind the envisioning and creation of the Faculty of Mathematics syllabus. Later, as a professor of Astronomy, he was chiefly responsible for the conception, planning and construction of the OAUC, as well as its instrument provision and subsequent scientific activity.

Monteiro da Rocha was the scientific mentor behind the applied mathematical and astronomical methods, algorithms, and tables that allowed the OAUC to establish and publish its most important and significant scientific production: the *Ephemerides Astronomicas* (EAOAUC). These first Portuguese ephemerides to be systematically calculated from the astronomical tables can be seen as Monteiro da Rocha's life project, which dates back to the 1760s when he wrote his manuscript about the longitude problem (Ms. 511). The quest for longitude, a central problem in the astronomy and nautical science of the late 18th and beginning of the 19th centuries, was the main motive for the creation of the Astronomical Observatory of the University of Coimbra.

From its inception and throughout its history, the OAUC tried to follow and contribute to contemporaneous astronomical research trends and developments. Celestial mechanics and its applications were the institution's main research topic until the 1850s. Later, it would pursue the new avenues that became available thanks to the development of astrophysics and, in particular, that of solar studies.

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